EUROPEAN COMMISSION

HORIZON 2020 PROGRAMME - TOPIC H2020-LC-GV-01-2018
Connected Electric Vehicle Optimized for Life, Value, Efficiency and Range

GRANT AGREEMENT No. 824295

CEVOLVER

Connected Electric Vehicle
Optimised for Life, Value,
Efficiency and Range

CEVOLVER – Deliverable Report

Report on specification of brand-independent E/E interfaces, communication protocols, interactions of VCU and cloud

Deliverable No.	CEVOLVER D1.1	
Related WP	WP2, WP3, WP4, WP5	
Deliverable Title	Report on specification of brand-independent E/E interfaces, communication protocols, interactions of VCU and cloud	
Deliverable Date	2019-03-29	
Deliverable Type	REPORT	
Dissemination level	Public (PU)	
Written By	Henrick Brandes, Ian Faye (ROBERT BOSCH GMBH) Olivier Lemaire (IFP Energies nouvelles) Bichen Chen, Patrick Manns, Alexander Wahl (RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN) Cedric de Cauwer, Joris Jaguemont (VRIJE UNIVERSITEIT BRUSSEL) Engelbert Trunner (ROBERT BOSCH AG) Andreas Schmitz, Jens Tang (FEV EUROPE GMBH)	2019-03-17
Checked by	Jens Tang (FEV EUROPE GMBH)	2019-03-17
Reviewed by (if applicable)	Markus Espig (FORD-WERKE GMBH) Vittorio Ravello (CENTRO RICERCHE FIAT SCPA)	2019-03-24
Approved by	Christof Schernus (FEV EUROPE GMBH)	2019-03-31
Status	Final	2019-03-31

Disclaimer/ Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824295. The information and views set out in this publication does not necessarily reflect the official opinion of the European Commission. Neither the European Union institutions and bodies nor any person acting on their behalf, may be held responsible for the use which may be made of the information contained therein.

1 Publishable summary

CEVOLVER focuses on a leap forward in user's confidence, functionalities and energy efficiency of future electric vehicle while ensuring their affordability by a user centric development approach.

Work package WP1 is setting the scene for the subsequent and partially in parallel starting work packages. The top-level description of the architectural elements and interfaces is the basis to detail out the system requirements after the use cases are defined and the resulting functions and features are identified. In other work packages (WP3, WP4, WP5), additional details regarding specific applications will add on to allow the build of the demonstrators and their testing.

The major deliverable of this report D1.1 is the definition of a technical implementation architecture. The methodology of Systems Engineering is adapted in this project to allow other work packages to start earlier as designated in the process and to reduce the overall project duration. The architecture is determined based on the state-of-the-art technologies and the already known boundaries of this project. A validation and potential adaptations of the architecture will be conducted after the functional decomposition during the ongoing project. Thus, the results depicted in this deliverable may not be final and alterations may be explained in later deliverables.

The determination of the technical implementation architecture is required to identify the needed brand-independent E/E interfaces and communication protocols. The original depiction of the interactions of VCU (Vehicle Control Unit) and cloud were enhanced by the complete interfaces in the targeted system of interest. The analysis is based on a differentiation between signal and physical interfaces in order to be able to design the powertrain and the communication architecture. The technical implementation architecture includes also the thermal system, the E-Powertrain, the vehicle internal connectivity units and alternative external devices to support the connectivity of the driver, the vehicle and external services.

2 Contents

2.1 Table of Figures

2.2 Glossary

AC	Alternate Current
ACC	Adaptive Cruise Control
ASIL	Automotive Safety Integrity Level
ASM	Asynchronous Machine
AUTOSAR	AUTomotive Open System ARchitecture
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAN	Controller Area Network
CCU	Connectivity Control Unit
CEVOLVER	Connected Electric Vehicle Optimised for Life, Value, Efficiency and Range
D1.1	Delivery 1.1
DC	Direct Current
E/E	Electric and Electrification
ECU	Engine Control Unit
EM	Electric motor
ESC / ESP	Electronic Stability Control
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HMI	Human Machine Interface
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
HW	Hardware
ICE	Internal Combustion Engine
IGBT	Insulated-Gate Bipolar Transistor
IP	Intellectual Property
LED	Light Emitting Diode

Lidar	Light Detection And Ranging
LIN	Local Interconnect Network
LTE	Long Term Evolution
LV	Low Voltage
LVDC	Low Voltage Direct Current
OBC	On-Board Charger
OEM	Original Equipment Manufacturer
PEU	Power Electronic Unit
PMSM	Permanent Magnet Synchronous Machine
PWM	Pulse Width Modulation
Radar	Radio Detection And Ranging
SE	Systems Engineering
SIM	Subscriber Identity Module
SOC	State Of Charge
SOH	State Of Health
SoI	System of Interest
SW	Software
TCP / IP	Transmission Control Protocol / Internet Protocol
USB	Universal Serial Bus
UMTS	Universal Mobile Telecommunication System
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to X (Infrastructure, Vehicle, …)
VCU	Vehicle Control Unit
WCDMA	Wideband Code Division Multiple Access
WP	Work Package

3 Introduction

3.1 Objectives

3.1.1 CEVOLVER

The current generation of electric vehicles have made significant progress during the recent years, however they have still not achieved the user acceptance needed to support broader mainstream market uptake. These vehicles are generally still too expensive and limited in range to be used as the first car for a typical family or for commercial usage. Long charging times and the strong dependence of the range on the environmental conditions are common as additional barriers to broader market success. For this reason, the CEVOLVER project takes a user-centric approach to create battery-electric vehicles that are comfortable and usable for long day trips whilst the installed battery is dimensioned for affordability. Hence the vehicles will be designed to take advantage of future improvements in the fast-charging infrastructure that many countries are now planning and installing. CEVOLVER tackles the challenge of executing even long trips with smaller batteries by making improvements in the vehicle itself to reduce energy consumption as well as maximizing the usage of connectivity in order to support the implementation of eco-routing and eco-driving. These features in turn rely on connectivity to support improving range prediction as a key element. Furthermore, the project includes optimization of both component and system design, as well as control and operating strategies. This will encompass measures that range over the on-board thermal management and vehicle energy management systems.

Within the project it will be demonstrated that long-trips are achievable even without further increase in battery size that would lead to higher cost, weight and energy consumption. The driver is guided to fast-charging infrastructure along the route that ensures sufficient charging power is available along the route in order to complete the trip with acceptable additional time needed for the overall trip. The efficient transferability of the results to further vehicles is ensured by adopting a methodology that proves the benefit with an early assessment approach before implementation in OEM demonstrator vehicles.

3.1.2 Current work package WP1

This work package shall set the scene for a connected energy and thermal management concept. The main objective of this WP1 is to select, define and specify the brand independent or common electric/electronic interfaces, brand-independent standards for communication with the cloud (external servers), and the data to be communicated. Further, it is intended to define use cases and driving profiles applied for user-centric development in subsequent WPs and to define requirements for controls of the BEV system.

3.1.3 Current task and deliverable T1.1 / D1.1

The first deliverable is intended to detail and document the agreements achieved in WP1 regarding the specification of interfaces and protocols and planned interactions with external servers (the cloud). The listed communication data will be limited to an agreed-upon brand-independent subset, as some data is security critical or IP blocked.

CEVOLVER shall adopt the methodology of systems engineering ("SE" - Details of SE in chapter 4.1.1). When following SE, the project would start by gaining a functional overview of the system of interest in CEVOLVER. Furthermore, this functional architecture would be followed by respectively mapping the functions into the corresponding technical solutions (e.g. HW modules). The resulting technical architecture would yield the required interfaces and their protocols.

However, on the other side, this would delay the start of subsequent work packages to detail out the needed simulation and the intended demonstrators. Thus, it was agreed within the proposal phase to set up a technical implementation architecture based on the best state-of-the-art knowledge and a generic view that supports the brand-independent ambition of the project.

Certainly, the resulting architecture would need to be verified and validated and requires potential adaptation loops after the steps according to systems engineering are conducted and their results are available. In detail, this would mean to verify the technical implementation architecture against the outcome of HIFI-ELEMENTS, which is another EU funded project focusing on standardization of deriving model interfaces. The project provides a set of vehicle topologies to describe to the largest extent the potential variants. The current status of HIFI-Elements would allow the comparison of the functional architecture with the vehicle topology and generate a set of interfaces needed to implement that topology. For more details on HIFI-ELEMENTS go to >> https://www.hifi-elements.eu <<. Eventually, the results shall be validated after the finalisation of Task T1.3 (Use-cases) and Task T1.4 (System requirements).

4 Methods and Results

4.1 Systems Engineering Approach

4.1.1 Generic approach

Systems have become increasingly complex over the recent years, especially when adding the new dimension of connectivity, along with involvement of inter-disciplinary partners and perspectives. Due to this complexity, it has become even more essential to deal with system development in a common and systematic approach in order to achieve a synergetic result. Modern systems engineering (SE) has become the accepted state-of-the-art in supporting the development of such systems.

The goal of SE is to tackle the challenge of system design and implementation in a holistic way to ensure that none of the essential aspects is neglected and the real problems are uncovered and addressable from the various perspectives. Thus, SE is intended to favor a stakeholder-oriented approach. It starts by defining the System of Interest (SoI) and identifying the requirements that all relevant stakeholders (e.g. users) would have when interacting with the SoI. At this point, the context must also be described and generally includes the surrounding components and subsystems that will not be modified during development, but provide data or boundaries for the SoI. The stakeholder requirements are first translated into system requirements, which in turn are the basis for defining high-level system functions and their interactions (functional architecture).

Entering the solutions space, possible technical realizations are drafted based on the functions, typically resulting in a more detailed level of (sub-)functions. In this process, functions will need to be mapped into the technical implementation in a step known as partitioning. Functions will be implemented generally in components where they are active and sufficient computational capabilities are available to implement the function. With consideration of the functional implementation, necessary interfaces between the components are determined and corresponding requirements on performance and quality are defined.

HIFI-Elements can be used at this point to confirm the interfaces. HIFI-Elements has set up several generic system topologies that are sufficiently detailed to be able to generate the interfaces necessary to implement a functional architecture. CEVOLVER would describe the target vehicle with one of the system topologies and use the functional architecture to derive the interfaces.

4.1.2 Adaptations to fit with CEVOLVER

CEVOLVER had to adapt the methodology of systems engineering to meet the time plan of subsequent work packages, which require the WP1.1 input to detail out e.g. the needed simulation and intended demonstrators.

Therefore, the process of defining and analyzing stakeholder and functional requirements and deriving a functional overview and architecture of the SoI is postponed. Thus, the first step is to start with a description of the technical implementation architecture and the interfaces based on the state-of-the-art. Due to this adapted process the current status of the technical implementation architecture described in chapter 4.2.1 may be required to be updated during this project when ongoing investigations and first simulation results are available.

Nevertheless, the current version of the SoI gives an initial overview about the interfaces of the (sub-) systems and components and provides a generic view that supports the brand-independent ambition of the project.

4.2 System of interest

4.2.1 Technical architecture based on state-of-the-art

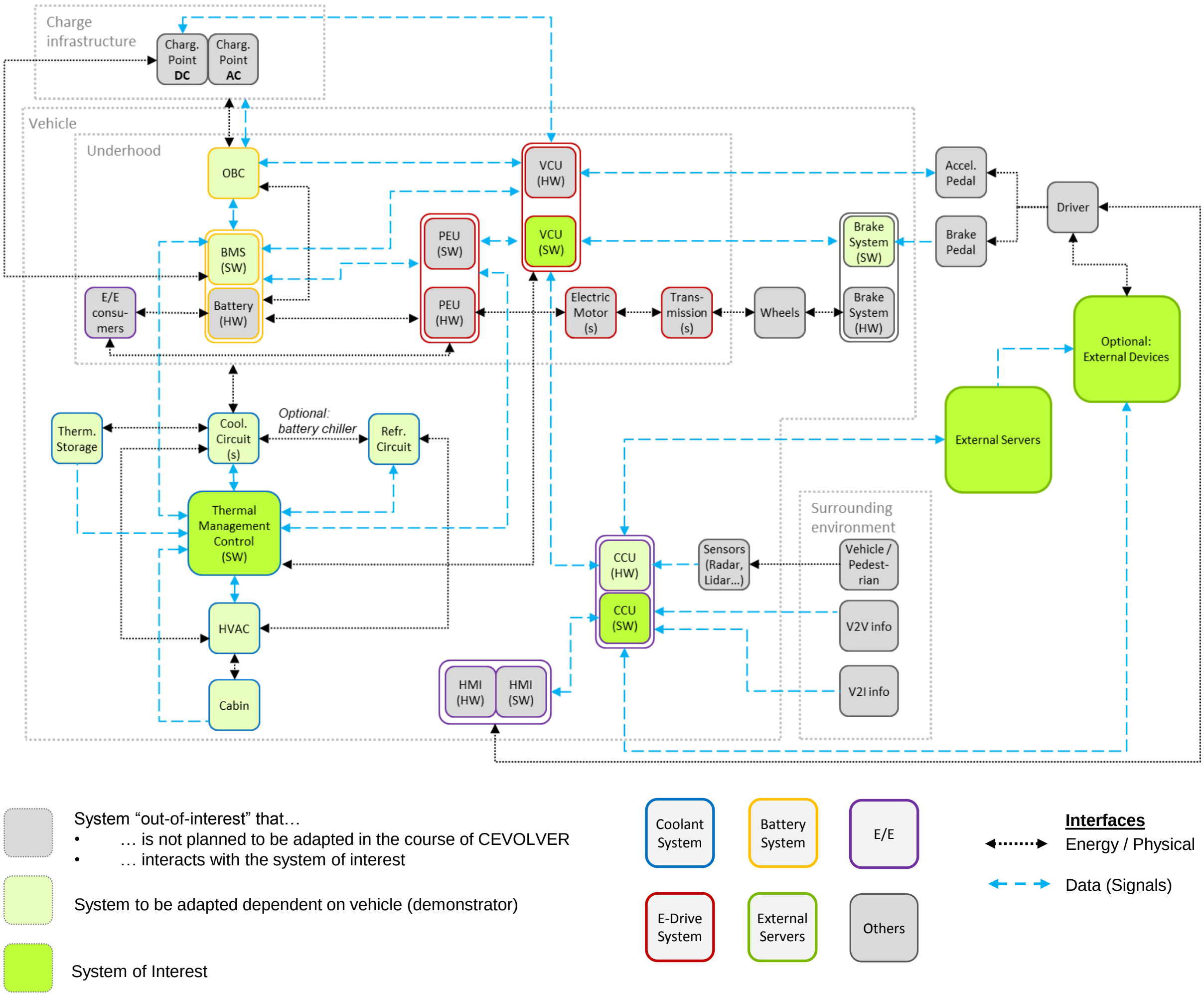

Figure 4.1 Technical implementation architecture view of System of Interest

4.2.2 System of external server(s)

While the term "cloud" is often described as a system including a dynamic range of applications, platforms and infrastructure, this report uses the term "external servers" to define the external hardware and the according interfaces that are required to serve the needs of CEVOLVER. Many other aspects as e.g. the applications of the "cloud" will be defined in subsequent tasks and work packages (e.g. WP2). "External" means in this report that an element is not part of the vehicle system. As an example, a tablet may be described that is inside the driving vehicle and operated by the driver. Still, it is an external element.

The external servers play a key role in the connected control strategies or functions. The external servers act as a gateway to provide neutral access to various data providers (weather, traffic, available charging points, ...) for the CEVOLVER connected functions. Moreover, they provide remote computing resources for heavy-duty computations, which do not need to be real-time and cannot be run on vehicle embedded computation unit(s) (cloud computing). They also serve as storage facilities, useful for energy network maps (energetic properties of road segments) required by the Eco-Routing service.

External servers include:

- OEM servers, which provide a direct connection to the vehicle, host proprietary services and act as a gateway to CEVOLVER services
- CEVOLVER servers, which provide neutral access to third party data providers as well as brand independent CEVOLVER services.
- third party data provider servers (open data or commercial):
    - Road network information
    - Traffic information
    - Weather forecast
    - Charging point infrastructure information

4.2.3 Human Machine Interface (HMI) and electronic Connectivity and Control Unit (CCU)

The HMI is the hardware unit that displays information to the driver and handles the driver's inputs (e.g. comfort preferences, trip data), communicating with the vehicle or external services (such as traffic info).
It can be embedded into the vehicle or external (mobile phone or tablet).
In the scope of CEVOLVER project, a tablet computer-based approach will be used to speed up prototyping and deployment.
In the case of the embedded device, the data processing is performed by the VCU.
In this document, "HMI" refers to the vehicle on-board device, "external device" refers to a mobile phone or tablet.

The CCU is an electronic Connectivity and Control Unit proposed to connect the vehicle with the outside world and provides data content from different data sources to other control units (e.g. ECU, VCU, ESP, …). It provides telematics and assistance services like emergency- and/or breakdown call as well as information services, remote control and diagnosis. Hardware features that may be included are e.g. LTE/WCDMA/GSM cellular modem & embedded SIM chip, GNSS receiver, Ethernet or CAN bus interface and high-speed USB.

4.2.4 Thermal system

The thermal system is one of the core elements of the CEVOLVER project. It consists of several subsystems that need to interact perfectly to find the efficient operating strategy, which are the cooling circuit, the HVAC, the refrigerant circuit, a thermal storage system, the cabin, and the thermal management control. The variety of tasks of the thermal system is very diverse and includes a multitude of subtasks.

The main task of the thermal system is to keep the component temperatures within a suitable operating range. This is ensured by the cooling circuit. The components of the cooling circuit and their quantity differ depending on the respective vehicle. In any case, the cooling system includes an electric coolant pump, a radiator, and the corresponding tubing. To consider the different operating temperatures of all components in the vehicle, in some cases more than one cooling circuit is used. Usually, a high and low-temperature circuit are implemented in the vehicle to cover all cooling requirements.

In addition, the thermal system must guarantee appropriate air conditioning of the vehicle cabin via mixing air of different temperatures in the HVAC in any ambient condition. The comfort function of the air conditioning may be assisted by functional surfaces directly supporting the temperature perception of the passengers. The functional surfaces usually deploy various heat transfer mechanisms as heat conduction (e.g. seat heating) and radiation to reduce the required target cabin temperature to achieve sufficient passenger comfort. However, not only the comfort of the driver plays an important role, but also the fulfillment of legal requirements, such as the prevention of window fogging. Therefore, the system must be capable of heating and cooling the ambient air and to provide a sufficient airflow into the cabin. To generate air temperatures inside the cabin, which are below the ambient temperature level, a refrigerant circuit needs to be added. The refrigerant circuit uses a phase change of the refrigerant to cool the air to lower temperatures and exchanges heat with the air inside the HVAC.

The conditioned air is distributed to the cabin by the HVAC, which typically has a radial fan to create an airflow into the cabin. Therefore, the ambient air is usually sucked in at an inlet right below the front window. Inside the HVAC the airflow is guided by plastic flaps, which can be controlled manually via mechanical connections or electronically. The air can either be taken from the ambient in fresh air mode or from the cabin itself in recirculation mode. In recirculation mode, the air, which is taken from the cabin, usually enters the HVAC at the footwell of the passenger. Nowadays there are systems that can realize any state between fresh air mode and recirculation model.

Usually, the refrigerant circuit and the cooling circuit are independent of each other. In some applications, the refrigerant circuit is connected to the cooling circuit via a chiller, which is a liquid-liquid heat exchanger. The Connection of the refrigerant and the cooling circuit enables the system to lower the temperature of the coolant below the ambient temperature. This feature is often used in BEVs to maintain the narrow temperature limits for the battery, even at high ambient temperatures. Nowadays the process of the refrigerant circuit can be reversed to use the system as a heat pump. This enables efficient heating at low ambient temperatures.

To improve the efficiency of the thermal system thermal storages could be implemented. These components save a certain amount of energy, which can be released when needed. For example, the cabin conditioning can be maintained during a traffic light stop by using the saved energy from the thermal storage.

4.2.5 E-Powertrain

The electrified powertrain is one of the central systems of the electric vehicle. It comprises several subsystems like battery system and electric drive system. The powertrain´s main task is to power the vehicle according to the driver demand and to store and provide the electrical energy in an energy-efficient way.

The battery system mainly consists of the chemical energy storage and battery management system (BMS). Due to the high-power level demand of the electric drive, the battery cells are connected in series and, depending on the selected cell capacity, in some cases also in parallel to battery modules. The battery modules are integrated into a battery pack to configure different sizes of energy content. While the single battery module itself remains usually below 60V DC (Class A limit) to allow an easy handling (no electric shock risk), the final battery pack provides mostly electric power with a high voltage level (>>60V DC, Class B) to reduce the losses of energy transfer to the high-power systems. This voltage asks for specific solutions to completely insulate the voltage source to avoid the electric shock risk.

Most electric vehicles include an on-board charger (OBC) so that the battery can be charged from an AC outlet. The OBC converts the provided AC voltage to DC voltage to charge the battery within a power level range of usually 3.5 kW (single phase with 16 A) to 22 kW (three phase connection with 32 A). The charger is designed for the specific battery in the car. In general, its algorithm is protecting the battery by adapting the charge power based on signals provided by the battery BMS (Battery Management System) as e.g. the temperature in critical areas of the battery.

Additional to the battery internal circuit, the BEV is usually designed with components taken over from conventional internal combustion engines (ICE) propelled vehicles. These are operated in low voltage circuits as e.g. 12V or 24V. Thus, the traditional low voltage applications (e.g. head lights) require the according low voltage circuits. Considering the electric machine(s) that propel the vehicle or recuperate inertia energy during braking based on a high voltage AC circuit there are several circuits with different voltage level and electric flow characteristic (AC / DC). The vehicle utilizes one or more PEU (power electronic unit(s)) consisting of inverters and converters to serve these circuit requirements. The PEU requires SW-based control algorithms to coordinate the electric circuits and protect the connected systems and components during operation.

The VCU (Vehicle Control Unit) as the central communication node receives all necessary data to control the vehicle´s energy management and control strategy. The VCU software containing e.g. the energy management is in the focus of CEVOLVER development whereas the VCU hardware will probably not be changed. Depending on its computing power, the VCU may also include the thermal management control.

For the propulsion of the vehicle, at least one electric drive system will be installed, which typically contains an EM (electric machine), a PEU (as described above) and a mechanical transmission. The combination is often integrated into an electronic drive unit, which is in turn integrated in the axle. The mounting position (rear, front), type of the electric machine (e.g. ASM – asynchronous machine, PMSM – permanent magnet synchronous machine) and number of the installed electric drive units is chosen depending on the vehicle´s application area. Due to the better compatibility of torque curve of an EM, when inverter driven, in comparison to the pull curve of the vehicle, the transmission is simpler than the transmissions for conventional ICE. The transmission is typically realized as a single reduction gear, but also a multi-speed transmission could be considered to fulfill the vehicle requirements. The hardware of the electric drive system will not be modified in CEVOLVER.

All electric powertrain sub-systems and components shall be developed and dimensioned according to the intended purposes and usage scenarios of the vehicle to avoid oversizing and to reach a high efficiency.

4.3 Electric and electronic interfaces

4.3.1 Physical interfaces

4.3.1.1 Physical Interface: External Devices – Driver

The driver interacts with the external device (tablet or mobile phone) reacting to instructions given by the CEVOLVER connected functions, such as eco-route or eco-driving, and providing trip preferences such as the destination, the route type, the charging location and the timing or duration deviation to fastest route.

4.3.1.2 Physical Interface: Sensors (Radar, Lidar) – Pedestrian / Vehicles

Sensors provide information about the vehicle environment such as speed and distance from the lead vehicle, pedestrian crossing the road. This information will improve the Eco-driving service by taking into account the surrounding environment.

4.3.1.3 Physical Interface: HMI – Driver

In general, HMI (human-machine-interface) describes any interaction between humans and machines.

Depending on defined E/E architecture, an HMI Controller is used to inform the driver about the system behavior or collect and provide data to the other computing modules. E.g. inputs to the system preferred by means of touch-screen, switches and/or selection wheels; feedback from the system to the driver/operator will be most likely by means of optical information, e.g. dashboard, head-up display, LED/warning lamps. Acoustic could also play a role for both inputs and outputs. Currently “haptic events” are not considered.

4.3.1.4 Physical Interface: HVAC - Cabin

The physical connection between the HVAC and the cabin is based on an exchange of airflows. Through the airflow both energy and fluids, such as air and water, are exchanged. By that, energy is transferred between both systems.

4.3.1.5 Physical Interface: HVAC – Refrigerant Circuit

For the cooling of the airflow, a heat transfer between the air and the refrigerant is needed. The transmitted energy is used to evaporate the refrigerant. The air releases so much heat that it cools below the ambient temperature. As a result, a cooling of the cabin can be ensured, even at high temperatures outside the vehicle. The heat transfer takes place in an air-liquid heat exchanger, which is also called evaporator in this special application.

4.3.1.6 Physical Interface: HVAC – Coolant Circuit

There is also an exchange of energy between the cooling circuit and the HVAC. For this purpose, usually, an air-liquid heat exchanger is used, transferring heat from the coolant to the airflow of the HVAC. The airflow afterwards enters the cabin in order to heat it up. In contrast to the connection to the refrigerant circuit, the energy is used to heat up the airflow. Therefore, the heat exchanger for the cabin heating is connected to the cooling circuit.

4.3.1.7 Physical Interface: Coolant Circuit – Thermal Storage

The thermal storage can be connected to the cooling circuit. Through this connection, an exchange of energy via a fluid flow can be realized. The heat of the coolant is used to melt the phase change material of the thermal storage. In this way, a larger amount of energy than in simple heating can be stored. In this way, more energy can be stored than with a simple warm-up of a material. The reversibility of the process ensures that the heat from the reservoir can be re-absorbed by the coolant. Another application of the thermal storage would be direct contact with a component or an integration into the refrigerant circuit.

4.3.1.8 Physical Interface: Coolant Circuit – Refrigerant Circuit

Energy can be exchanged between the cooling circuit and the refrigerant circuit. Therefore a chiller is implemented to the system. This liquid-liquid heat exchanger connects both circuits energetically. There is no exchange of any fluid between the circuits. The energy exchange can either be used to cool down the coolant below the ambient temperature to maintain battery temperature limits or to heat up the coolant at low ambient temperatures. The second variant can only be used, if a heat pump operation is possible.

4.3.1.9 Physical Interface: Coolant Circuit – Underhood

The underhood in this case of the depicted technical implementation architecture is a representative for the sum of all components inside the so-called engine compartment. These components are thermally connected with the cooling circuit. Thus, the coolant circuit is operated in order to heat up or cool down the components, depending on their current state and the ambient conditions.

4.3.1.10 Physical Interface: Battery – E/E consumers

The physical interface between the high voltage E/E consumers and the battery is a direct high voltage DC link.

Figure 4.2 Physical interface: Battery – E/E consumers

4.3.1.11 Physical Interface: Battery - PEU

A high voltage link capable of transmitting peak battery power connects the battery and the PEU. The battery feeds the PEU to convert DC to AC in order to interact indirectly with the EM.

Figure 4.3 Physical interface: PEU – Battery

4.3.1.12 Physical Interface: Battery – Onboard Charger

For the charging of the battery, the OBC and the battery exchange energy via a high voltage link. The OBC or rectifier charges the battery by converting the grid AC to DC and controls the charging that a targeted state of charge is reached.

Figure 4.4 Physical interface: Battery – OBC

4.3.1.13 Physical Interface: Onboard Charger – Charging Infrastructure

In case of AC charging, grid electric power (AC) is transferred towards the OBC from the charging point AC. The electric power is used to charge the battery.

If the high-power DC charging is realized by CCS2 (Combined Charging System 2.0) the according connector based on IEC 62196-3 routes the protected earth (PE) through the AC charging pins of the connector and by that through the onboard charger (OBC).

4.3.1.14 Physical Interface: Battery – Charging Point DC

If the battery is connected to a charging point DC, the OBC or rectifier is not needed to convert AC to DC. In this physical interface, the battery is directly charged with HV DC by the charging point in order to charge the battery to a specific level.

Figure 4.5 Physical interface: Battery – Charging point DC

4.3.1.15 Physical Interface: PEU – E/E consumers

It is assumed that the PEU includes a DC/DC converter, which receives HV DC from the battery and converts the current to LV DC in order to serve the electrical loads of the auxiliary consumer(s) operated in low voltage.

Consequently, the losses generated by the conversion need to be considered. This device is in general one way and, if linking Class B to Class A voltages, has to be galvanically insulated.

Figure 4.6 Physical interface: PEU - E/E consumers

4.3.1.16 Physical Interface: PEU – Electric Motor(s)

Usually, the PEU and electric motor are supplied as a dedicated combination. During vehicle propulsion, the inverter converts a direct current (DC) into an alternating current (AC) to power the electric motor. In recuperation phases, the EM transfers the generated electric power to the PEU, which converts the alternating current (AC) into direct current (DC) to charge the battery. The EM provides analog signals of rotor position and speed sensor (resolver) and temperature sensors to the PEU, which are necessary for the PEU control strategy. Usually, a coolant flow is transferred from the PEU to the EM in order to cool down firstly the PEU and subsequently the EM. Alternatively, the EM is cooled by transmission oil.

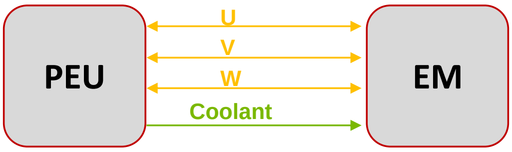

Figure 4.7 Physical interface: PEU – EM

4.3.1.17 Physical Interface: Electric Motor(s) – Transmission

The EM and transmission are physically connected in order to transfer mechanical energy and power (torque, speed).

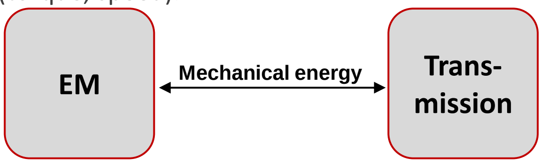

Figure 4.8 Physical interface: EM – Transmission

4.3.1.18 Physical Interface: Transmission – Wheels

The transmission(s) are physically connected to the wheels to transfer mechanical energy in both directions (propulsion, deceleration via recuperation).

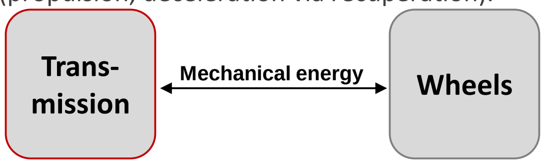

Figure 4.9 Physical interface: Transmission – Wheels

4.3.1.19 Physical Interface: Wheels – Brake System

The wheels are physically connected to friction brakes. The vehicle can be decelerated either by the friction brakes, the EM working in generator mode or a combination of both.

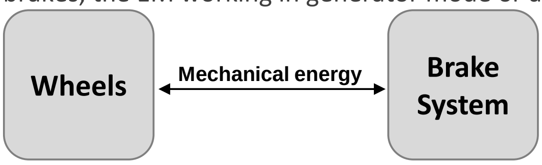

Figure 4.10 Physical interface: Wheels – Brake System

4.3.1.20 Physical Interface: Driver – Accelerator Pedal

The driver steps on the accelerator pedal for requiring either wheel torque according to the position of the accelerator pedal or speed of the vehicle, assuming preferably one-pedal driving.

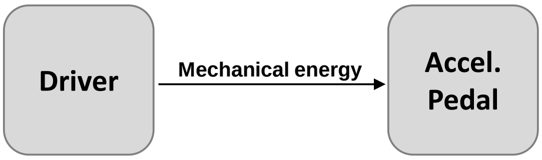

Figure 4.11 Physical interface: Driver - Accelerator Pedal

4.3.1.21 Physical Interface: Driver - Brake Pedal

The driver steps on the brake pedal for requiring brake torque according to the pressure/force of the brake pedal.

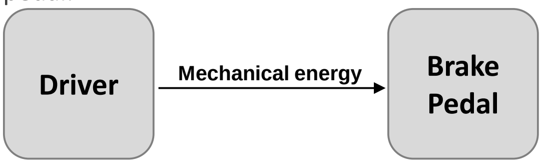

Figure 4.12 Physical interface: Driver - Brake Pedal

4.3.2 Signal interfaces

4.3.2.1 Signal Interface: External Servers - External Device

An external device such as a tablet or mobile phone can be used instead of the vehicle's HMI. It requests data (weather information, traffic info, etc.) from external servers via the cellular data network, which are needed to perform local functions such as Eco-driving, or displays the results of remote functions performed on external servers. Aside from requesting data, this connection sends user inputs to the (OEM) cloud like the desired destination or drivers preferences.

4.3.2.2 Signal Interface: External Servers - CCU

CCU sends requests to external servers through cellular data network to obtain external data (e.g. weather, charging point locations and traffic information for a given GPS location) needed to fulfill onboard services and shares vehicle data for the remote connected functions (e.g. eco-routing). CCU sends a signal to trigger a calculation on the external sever.

4.3.2.3 Signal Interface: CCU - External Device

An external device, such as a tablet or mobile phone, requires the CCU to:

- send driver preferences to remote services (e.g. Eco-Routing) hosted on external servers
- obtain vehicle information (e.g. battery and e-powertrain information) used by the CEVOLVER functions (e.g. Eco-routing or smart-charging)
- obtain data via CCU (e.g. weather and traffic information) over the Internet to perform local functions (e.g. eco-driving) on the external device
- display the results of the CEVOLVER functions performed on external servers, on VCU or on external device

They communicate via a cellular network, a CAN bus or Bluetooth.

4.3.2.4 *Signal Interface: CCU – HMI*

CCU and HMI (as an alternative to the external device) are typically connected directly - or via an additional application unit, such as an IVI (In-Vehicle Infotainment) device – by TCP/IP or CAN protocol. User inputs to the vehicle (e.g. desired speed, comfort preferences, trip data) are entered into the HMI and communicated through the CCU to the VCU.

Figure 4.13 Signal interface: CCU - HMI

4.3.2.5 *Signal Interface: CCU - VCU*

The interface (VCU/CCU) shall be a reliable and secure communication channel between the VCU and external servers in order to ensure a trusted data provision for V2X, V2I and V2V communication.

Depending on implemented functionality, served data could be as follows:

- Information regarding vehicle surroundings, such as speed and trajectory of other vehicles (e.g. to signal a vehicle ahead performing an emergency braking maneuver).
- Extended perception beyond the limits of the in-built vehicle sensors.
- Map data, enhanced by dynamic external server-based data (e.g. availability of charging station, latest map data, plus information on road and traffic conditions)
- Traffic flow, inclines, bends, speed limits, congestion end, road surface condition

Ethernet communication with > 100 Mbit/s is recommended. In addition, service oriented communication paradigms such as SOME/IP are currently established to provide hardware independent application interfaces between dynamically available functions both within the vehicle and hosted by the external server.

Figure 4.14 Signal interface: CCU - VCU

4.3.2.6 *Signal Interface: CCU – Sensors (Acceleration, Thermal)*

Typical sensors connected to the CCU are temperature-, acceleration and gyro-sensor. In contrast to this, the related information of sensors like RADAR, front camera and/or LIDAR are usually provided to the "Driver Assistance System Domain" Controller or ACC control units.

These sensors would be typically connected via a statically configured communication medium such as CAN providing sensor specific signals at a fixed cyclic rate and priority.

Figure 4.15 Signal interface: CCU - Sensors

4.3.2.7 Signal Interface: CCU - V2X

As mentioned in section 4.3.2.5, V2X mainly consists of V2I and V2V. Thus, the communication of V2V provides information about other vehicles such as the distance to a leading vehicle or its speed. On the other hand, V2I covers information about the infrastructure like dynamic speed limitations and traffic light switching times.

V2X communication provide useful information to the Eco-driving function such as lead vehicle braking event or speed, dynamic speed limitation, traffic light time to change. It uses standard communication protocols 802.11p or C-V2X.

4.3.2.8 Signal Interface: Thermal Management Control - Refrigerant Circuit

The thermal management control demands various sensor values of the refrigerant circuit. These include, for example, the pressures and temperatures of the refrigerant at the various points of the circuit, the current position of the thermal expansion valve and the current electric compressor speed. Based on this information the thermal management control sends a signal to control the electric compressor. This signal can be transmitted, for example, by a LIN bus. Although many thermal expansion valves are still self-regulating, there is already the possibility of controlling them via an electrical signal.

4.3.2.9 Signal Interface: Thermal Management Control – VCU

The VCU is typically responsible for the energy management and vehicle control strategy. The thermal management control would be implemented on the VCU or a devoted thermal management unit depending on their computing power and, in the first case, would interact as a (sub-)function with other VCU functions. The thermal management control provides data like temperatures (e.g. battery, PEU, EM) and actual power of auxiliary consumers (e.g. pumps, compressor) to relevant functions running on the VCU. If the thermal management is located on a separate device, the communication is usually done via CAN.

4.3.2.10 Signal Interface: Thermal Management Control - HVAC

The thermal management control needs sensor values from the HVAC in order to provide a conditioned airflow. The usually required information in order to control the air conditioning is air temperature and air humidity. The thermal management control then actuates the different flaps in order to mix the different airflows inside the HVAC to maintain the desired cabin temperature. The flaps are controlled by small electric motors using a PWM (pulse width modulation) signal. In basic systems, the air outlet of the HVAC is not controlled by the thermal management control. For these systems, the driver has to adjust the air outlet manually.

4.3.2.11 Signal Interface: Thermal Management Control - Cabin

For regulating the air temperature inside the cabin the thermal management control needs information about the current air temperature of the cabin. In some cases, the information about the humidity of the cabin air is transferred as well, as it has an impact on the thermal comfort perception of the passengers.

The cabin only provides information about its state, while the thermal management control actuates the different components inside the HVAC in order to manipulate the conditions within the cabin. In order to increase the comfort, air quality sensors are used in modern vehicle cabins to switch between the recirculation and fresh air mode. Also, additional heating equipment can be implemented in the cabin to improve the comfort perception of the passengers. Such devices, for example, steering wheel heating, seat heating or radiation surfaces, are then controlled by the thermal management control.

4.3.2.12 Signal Interface: Thermal Management Control - Thermal Storage

For the integration of the thermal storage, which may be used in CEVOLVER, three different temperatures are needed. On the coolant side, the in- and outlet temperature at the storage are measured. In addition to that, the current storage temperature is monitored. Therefore, thermal sensors like Pt100 or thermocouples can be used and provide a voltage signal, which has to be interpreted by the thermal management control. The coolant volume flow through the thermal storage can be used to regulate its temperature. This is also important to manage the saved energy inside the system.

4.3.2.13 Signal Interface: Thermal Management Control - Coolant Circuit

The thermal management control receives sensor values from the cooling circuit. These values are temperature, pressure and volume flow signals. Based on this information the built-in coolant pumps are controlled, usually via LIN or PWM signals. A control of various valves might be required if the cooling circuit is more complex. These valves can, for example, be used to separate or connect different circuits depending on the relevant thermal control strategy for the current situation.

4.3.2.14 Signal Interface: Thermal Management Control - Battery

As the temperature limits for the battery are very narrow, these have to be properly monitored. To prevent damage to the cells, and potential vehicle fires due to the thermal runaway mechanism, the temperature limits must not be exceeded at any time. The thermal management control therefore receives information about the current battery coolant inlet temperature and battery cell temperature. Based on this information the thermal management control decides if the current cooling strategy must be adapted. An enduring exceeding of temperature limits of the battery leads to a degradation of the battery performance and finally to its failure.

4.3.2.15 Signal Interface: Thermal Management Control - PEU

The power electronics of the vehicle also have limitations to their maximum temperatures and therefore are monitored with a temperature measurement device like a Pt100. For the inverter, the temperatures at the power switches (e.g. IGBTs) and the diodes are the most critical ones. If these temperatures approach their threshold, the power output is reduced. For the converter, the temperature of the electronics is also restricted and therefore monitored. The relevant temperature values of the inverter and the DC/DC converter are transmitted to the thermal management control. In order to prevent any violation of the temperature limits, the thermal management control operates the cooling circuit according to a chosen strategy.

4.3.2.16 Signal Interface: VCU - PEU

The VCU typically receives data like min./max. available torque and power as well as actual speed and torque of the electric motor from the PEU in order to adapt the control strategy. The VCU provides the PEU with information about the driver torque request, which is used to calculate the intensity of electric current for powering the EM. The signals would usually be transferred e.g. via a dedicated high-speed CAN.

4.3.2.17 Signal Interface: VCU – BMS (Battery)

The VCU receives battery specific information from the BMS (Battery-Management-System) to coordinate and control the system energy management. These signals provide information about the battery status, SOC (state of charge), SOH (state of health) and further physical data such as temperature. Furthermore, the actual output current and voltage and the power limits for charging und discharging are sent to the VCU typically via CAN.

4.3.2.18 Signal Interface: VCU - Accelerator Pedal

The relevant signal here is the driver's input to maintain or change the speed of the vehicle: e.g. actuate to increase or decrease, assuming preferably one-pedal driving.

This sensor would typically be connected via a statically configured communication medium such as CAN providing sensor specific signals at a fixed cyclic rate and priority. Due to the safety-related nature of the sensor, several redundant readings will typically be taken and combined with plausibility checks to ensure the integrity of the signal. In addition, an End-to-End Protection mechanism, for example, as defined by AUTOSAR will typically be used to ensure the integrity of the transmission of the signal.

4.3.2.19 Signal Interface: VCU - Brake System

The relevant signal here is the driver's (or potentially safety system) input to decrease the speed of the vehicle. Signal as set-point for the brake system ensures the right brake torque to optimize recuperation. Using one-pedal driving a coordinated control of brake- and recuperation system is required.
The braking system would be typically connected via a statically configured communication medium such as CAN providing sensor specific signals at a fixed cyclic rate and priority. Due to the safety-related nature of the braking system, the safety integrity level (ASIL) of the system calculating the braking demand would need to be argued or explicit plausibility checks of the provided braking demand signal built into the braking system itself. In addition, an End-to-End Protection mechanism, for example, as defined by AUTOSAR will typically be used to ensure the integrity of the transmission of the signal.

4.3.2.20 Signal Interface: VCU - OBC

During the charging process, the OBC provides signals like the charging status, actual energy transfer (e.g. power, current, voltage), power limitations and the OBC temperature to the VCU. These signals could be provided e.g. via CAN.

4.3.2.21 Signal Interface: VCU - Charging Point DC

Before the charging process can start, the charging point DC needs information about the vehicle status and maximum limits. Therefore, the VCU usually provides data describing the status for example like ready-for-charge and additionally the maximum DC supply output current and voltage. The charging point DC provides information about the cable and isolation status before the charging process starts finally.
In some electric vehicle types this communication is handled by the onboard charger.

4.3.2.22 Signal Interface: VCU – Sensors (Radar, Lidar)

The related information of sensors like RADAR, front camera and/or LIDAR are usually provided to the "Driver Assistance System Domain" Controller or ACC control units. Relevant data and information regarding surrounding traffic (e.g. preceding vehicle) are provided to the VCU.

4.3.2.23 Signal Interface: PEU – BMS (Battery)

The signal interface between PEU (Inverter) and BMS is an exchange of battery voltage, maximum and minimum allowed charging and discharging voltage, battery current and status of main contactors in order to provide the requested power within the voltage and current limits.

4.3.2.24 Signal Interface: Brake System - Brake Pedal

The brake pedal is usually realized as a conventional pedal or as an electric brake pedal. The conventional brake pedal hydraulically actuates directly the friction brakes and provides just information like for example brake status and brake pressure. Redundant signals would also be transferred due to safety reasons. An electric brake pedal does not directly actuate the friction brakes but provides data about the driver´s brake demand (brake by wire). The brake system coordinates the distribution of the brake demand to the EM working in generator mode and actors, which actuate the friction brakes. As mentioned in chapter 4.3.1.19 the safety integrity level (ASIL) of an electric brake pedal would need to be argued.

4.3.2.25 Signal Interface: Onboard Charger – Battery

During the charging process, the signal interface between the battery and the OBC consists of an exchange of signals in order to perform a correct charging process. Examples for exchanged signals are the voltage level, current, SOC and battery temperature.

4.3.2.26 Signal Interface: Onboard Charger - Charging Infrastructure

The signal interface between the OBC and the charging point AC is an exchange of the battery voltage level, current level and battery SOC in order to coordinate a correct charging process.

Furthermore, before starting the charging process, the charging point needs information about the vehicle status and maximum limits. Independent of AC or DC charging the OBC usually provides data describing the status for example like ready-for-charge and additionally the maximum supply output current and voltage. The charging point provides information about the cable and isolation status before the charging process starts finally.

5 Summary and recommendations

CEVOLVER focuses on a leap forward in user's confidence, functionalities and energy efficiency of future electric vehicle while ensuring their affordability by a user centric development approach.

This work package is setting the scene for the subsequent and partially in parallel starting work packages. The top-level description of the architectural elements and interfaces is the basis to detail out the system requirements after defining the use cases and identifying the resulting function and features.

The step of defining a technical implementation architecture is a major deliverable of this report. The methodology of Systems Engineering is adapted in this project to allow other work packages to start earlier as designated in the process and to reduce by that the overall project duration. The architecture is determined based on the state-of-the-art technologies and the already known boundaries of this project, a validation and potentially required adaptations of the architecture will be conducted after the functional decomposition during the ongoing project. Thus, the results depicted in this deliverable may not be final and alterations may be explained in later deliverables.

The determination of the technical implementation architecture is required to identify the needed brand-independent E/E interfaces and communication protocols. The original depiction of the interactions of VCU and cloud were enhanced by the complete interfaces in the targeted system of interest. This includes also the thermal system and the E-Powertrain as also the vehicle internal connectivity units and alternative external devices to support the connectivity of the driver, vehicle and external services.

The report includes:

- A short description of the tasks of this report D1.1 on basis of the relevant part goals for CEVOLVER and this work package WP1
- An adapted systems engineering approach with argumentation that it is suiting our needs
- Technical implementation architecture as developed in task T1.1
- Presentation of the main (sub-)systems and their components E-Powertrain, Thermal Systems, Communication elements
- Description of the (physical and signal) interfaces

6 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner	Partner Full Name
1	FEV	FEV Europe GmbH
2	BOSCH	Robert Bosch GmbH
3	FORD	Ford-Werke GmbH
5	IFPEN	IFP Energies Nouvelles
6	RWTH	RWTH Aachen University
7	VUB	Vrije Universiteit Brussel
8	UNR	Uniresearch BV
9	I2M	I2M Unternehmensentwicklung GmbH
10	RBOS	Robert Bosch AG
11	CRF	Centro Ricerche FIAT SCPA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 824295